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Interelectronic interaction in dirty FS trilayers: A manifestation of "hidden" superconductivity

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ABSTRACT

The properties of the ferromagnet/superconductor (FS) system are theoretically studied. Electron–electron pairing interaction in F layers is taken into account. The boundary value problem for the Usadel-like equations is considered in the case of so-called "dirty" limit. It is shown that both asymmetry and interelectronic interaction essentially influence on the critical properties of the F_1SF_2 trilayer. The appearance of the solitary superconductivity is predicted for this asymmetrical trilayer.

1. Introduction

It is well known that in artificial layered structures consisting of the superconductor (S) and ferromagnet (F) layers, the interplay between the S and F parameter orders can lead to a several striking phenomena such as the nonmonotonic behaviors of the critical temperature and the Josephson current as a function of the ferromagnetic layer thickness [1–3]. In particular, re-entrant and periodically re-entrant superconductivity was predicted in works [4–6]. Later the re-entrant superconductivity experimentally was discovered in bilayers V/Fe [7] and $Nb/Cu_{1-x}Ni_x$ [8]. Note, a solitary superconductivity was also recently theoretically proposed in clean FS system [9,10] . Most recently, the appearance of peculiar solitary re-entrant superconductivity caused by external magnetic field is predicted for the F_1F_2S system [11].

The coexistence of two antagonistic phenomena in FS systems is possible due to the proximity effect [12]. The superconducting correlations can penetrate from the S layer into the F layer, even though there is no pairing interaction and, consequently, the superconducting order parameter vanishes. The singlet superconducting correlations decay on very short distance $\xi_I = \sqrt{D/I}$ (where I is exchange field and D is diffusion constant in F) into the ferromagnet layer [1–3,13,14]. For strong ferromagnets such as Fe, Ni or Co the decay depth is approximately few nanometers.

There is great interest to these FS layered heterostructures due to possible spin valve applications. Thus the spin valve device based on the three layered FS systems switched by weak external magnetic field was proposed in works [15–17]. Changing the mutual orientation of the magnetizations of the ferromagnets can control the critical temperature T_c of these systems, and, therefore, the switching between two different states, i.e. the superconducting state with antiparallel (AP) orientation of the magnetizations of F layers and the resistive state with parallel (P) one. Note that the superconducting switch based on the fourlayered FSFS system can have up to seven different states [18].

An electron–electron interaction in a ferromagnet (F) was neglected in the standard approach to the proximity effect theories for the layered SF structures (see for example [1–3] and references therein). In other words a superconducting order parameter Δ_f and an interelectronic interaction constant λ_f were taken as zero for a ferromagnet. Actually this interaction exists, but it is suppressed by strong exchange field I and can be reveal itself if an exchange field disappears. So, in this case a ferromagnet is transformed to normal metal and that "unhidden" interelectronic interaction can lead to superconducting correlations and, therefore, a superconductivity onset with critical temperature T_{cf}, estimated by the standard BCS expression.

Previously we shown that a consideration of this interaction in the clean FS structures limit [19–21] can explain a surprisingly high critical temperature T_c ($T_c \sim 5$ K) in the short-periodic Gd/La superlattice [22,23]. Note that gadolinium is a strong ferromagnet with a Curie temperature $T_C \simeq 290$ K.

Below we analyze this problem for dirty case based on solutions of boundary value problem for the Usadel function, changing different parameters of asymmetrical F_1SF_2 trilayer (thicknesses of layers, boundary transparencies, and so on). Taking into account an interelectronic interaction leads to an appearance of "hidden" superconductivity of F layers which can be manifest itself in the

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